Leonardo da Vinci on atherosclerosis and the function of the sinuses of Valsalva

B. Boon

Although well studied by a medical scholar like Kenneth D. Keele,[1] Leonardo da Vinci's elaborate study of the heart is not generally known. This article focuses on two of Leonardo's achievements concerning atherosclerosis and the sinuses of Valsalva.[2] The first is his post-mortem observation on the degeneration of the vascular system in an old man, an early case history. The second is his discovery of the haemodynamical function of the sinuses of Valsalva in the closure mechanism of the aortic valve. This discovery remained hidden for many centuries, to be confirmed by scientific research not earlier than 1969. His observations will be discussed by showing the evidence: the notes and drawings in Leonardo's notebooks which he used to keep up as a diary of ideas.

Atherosclerosis: a peaceful death

Somewhere between 1504 and 1508, Leonardo da Vinci (1452-1519) met a very old man in the hospital of Santa Maria Nuova in Florence, who told him he was a hundred years of age and did not feel, in Leonardo's own words, 'any bodily ailment other than weakness'. However, while Leonardo was at his bedside, the centenarian suddenly passed away 'without any movement or sign of anything amiss'.[3]

Then Leonardo did something remarkable for a man without medical training: 'I made an autopsy in order to ascertain the cause of so peaceful a death, and found that it proceeded from weakness through the failure of blood and of the artery that feeds the heart and the other lower members, which I found to be very dry, shrunken and withered.'[4] Since 'the artery that feeds the heart' also feeds 'lower members', this passage does not refer to a coronary artery but probably to the aorta.

B. Boon
Netherlands Society of Cardiology (NVVC), Utrecht, the Netherlands

Correspondence to: B. Boon
Netherlands Society of Cardiology (NVVC), PO Box 19192,
3501 DD Utrecht, the Netherlands
E-mail: boon@nvvc.nl

Leonardo continues: 'the old who enjoy good health die through lack of sustenance, and this is brought about by the continuous narrowing of the passage of the mesenteric vessels by thickening of the coats of these vessels'.[5] It is important to realise that Leonardo was not aware of the concept of circulation. He sees the vascular system as a one-way street and therefore believes that the narrowing of the vessels starts near the source of sustenance, that is the digestive system. This remark is followed by: 'and the process continues until it affects the capillary vessels which are the first to close completely, and from this it comes to pass that the old fear the cold more than the young, and that those who are very old have their skin the colour of wood, or of dried chestnut, because this skin is almost completely derived of sustenance.'[6] It is clear that Leonardo realised that the process of ageing is linked to degeneration of the vessels. As he put it in one of his many metaphors: 'this coat of the vessels acts in man as in oranges, in which the peel becomes thicker and the pulp diminishes the more they become old.'[7]

Leonardo also theorises on the cause of the degeneration of the vessels: 'I consider that a thing which is nearer to that which feeds it increases more, and for this reason these vessels being a sheath of the blood that nourishes the body it nourishes the vessels so much the more as they are closer to the blood.'[8] This quote states that the thickening of the intima is due to nourishment of the blood they contain, which brings to mind the role of cholesterol in atherosclerosis.

In the days of the autopsy on the centenarian, Leonardo also did an autopsy on a two-year old child: 'here I found everything the contrary to what it was in the case of the old man.'[9] He makes an interesting observation: 'the vessels in the old acquire great length and those which used to be straight become bent, and the coat thickens so much that they close themselves up and stop the movement of the blood.'[10]

Tortuous vessels in old people were of special interest to Leonardo. On another page he remarks: 'when the vessels become old they lose the straightness of their branching and become more folded or tortuous.'[11] An explanation for this he finds in his study of hydrodynamics.

Hydrodynamics and haemodynamics

Hydrodynamics was one of Leonardo's many fields of interest. Looking at his drawings, one feels the pleasure with which he draws vortices not only in his depiction of water but also for example in the curly hair of male and female models. The artist in Leonardo must have felt a sense of beauty looking at arabesques and semicircles.

In one of his notebooks Leonardo describes an experiment in which he studies the bouncing of a current of water against the sides of a glass-walled pipe. By putting little particles in the water, he makes the current visible and observes that the course of the current in the pipe is not straight, but tortuous like a snake. This explains why the course of a river like the Arno is not straight, Leonardo states. The water is continually bouncing against the banks and as time passes by the course of the river gets more and more tortuous. The older the river, the more tortuous it is.[12]

These hydrodynamic observations were probably in his mind when Leonardo discussed the tortuous vessels in old people. An analogy between the macrocosmos of nature and the microcosmos of the human body is common in his thinking. Even more than in his study of the vessels in old people, his understanding of hydrodynamics was the key to his discovery of the function of the sinuses of Valsalva.

The function of the sinuses of Valsalva

In 1969 and the following years Brian Bellhouse and his group published a series of articles on the mechanics of the aortic valve.[13] The authors describe experiments in which a transparent model of the aorta with a flexible valve was perfused by water. Small particles in the water made the current visible and the flow pattern was recorded through a new technique, cinematography. The principal observation was that eddy currents in the sinuses of Valsalva cause the leaflets to approximate even before the systole is completed. Therefore only minimal reversed flow for final valve closure is required and regurgitation does not occur.

In 1991, Francis Robicsek published an article in which he shows that Leonardo da Vinci described the same principle and even executed a similar experiment as the Bellhouse group.[14] His article is a spectacular juxtapostion of two comparable studies on the aortic valve, separated by more than 450 years, with nothing of its kind in between. However, Robicsek assumes that Leonardo *executed* the experiment he describes, but a close reading of the note in question makes this doubtful: 'a plaster mould *to be* blown' [..].[15] Obviously Leonardo is only toying with the idea of such an experiment. Let's have a closer look at the evidence.

The Royal Library in Windsor Castle is famous for its pages with Leonardo's drawings of the heart, of which several can be dated rather precisely because Leonardo wrote on one of the pages: 9 January 1513. For stylistically related pages in the same collection this date is usually adopted. Several pages are completely dedicated to the aortic valve, containing small drawings of curly vortices near the aortic valve and many written notes on this subject.[16] The page shown here (figure 1) is indicative for the evidence. It shows drawings of an aortic mould (figure 1A) and artificial valves (figure 1B), plus a drawing of the right ventricle (figure 1C) and a drawing of the left ventricle with the aortic valve and vortices in the sinuses of Valsalva (figure 1D).

The drawing of the left ventricle shows a remarkable feature: a moderator band of a sturdy kind that is found in bovine hearts (figure 1D). Most scholars agree that Leonardo used a bovine heart for all his drawings from around 1513, for which he may have had two reasons. Firstly a human heart was not always available, even for a man like Leonardo, and secondly a bovine heart is larger and therefore details like the coronary arteries are easier to grasp. Leonardo himself mentions a bull's heart in a note (figure 1A): 'pour wax into this valve of a bull's heart so that you may see the true shape of this valve'.[17]

The drawings illustrate the level of Leonardo's knowledge of the aortic valve and of the haemodynamics in the sinuses of Valsalva, but it is the notes that make us part of his line of thought. In a note on a stylistically related page on the aortic valve that is not reproduced here, Leonardo describes the haemodynamics in the sinuses of Valsalva: 'on the reopening [diastole] of the left ventricle the blood contained in it ceases to escape from the ventricle, and at that time the escaping blood would attempt to return into this ventricle together with that which lies above it, but the remainder of the revolving impetus which still exists in the escaping blood is that which with this revolving beats against the sides of the three valves and closes them so that the blood cannot descend'.[18]

A note next to the little drawing with the wrinkled cusp (figure 1E) describes a part of the problem for which the haemodynamics in the sinuses of Valsalva form the solution. The current of blood which closes the aortic valve has to be lateral and not perpendicular, because the cusps would get wrinkled: 'the blood which turns back when the heart reopens is not that which closes the valves of the heart, this would be impossible because if the blood beats against the valves of the heart while they are corrugated, wrinkled and folded, the blood which presses from above would weigh and press down the front of the membrane upon its origin, as is shown at the valve r o [figure 1E, note the letters r and o], the folds of which, being weighted down from above, would close in solid contact, whereas Nature intended it to be stretched in height and width'.[19]

Finally we will have a closer look on Leonardo's toying with the idea for an experiment. The upper end of the aortic mould (figure 1A) is marked by the letter 'a' and the lower end by the letter 'n'. The note in between reads: 'a plaster mould to be blown with thin glass inside and then break it from head to foot at [the letter] a [and the letter] n, but first pour wax into this valve of a bull's heart so that you may see the true shape of this valve'. The drawings of valves on the left (figure 1B) do not have notes but there can be little doubt that they are tryouts to investigate 'the true shape' of the valve, which would complete the aortic mould. Interesting as these drawings and the short note may be, they are far from being a report about an executed experiment to prove the theory on the function of the sinuses of Valsalva.

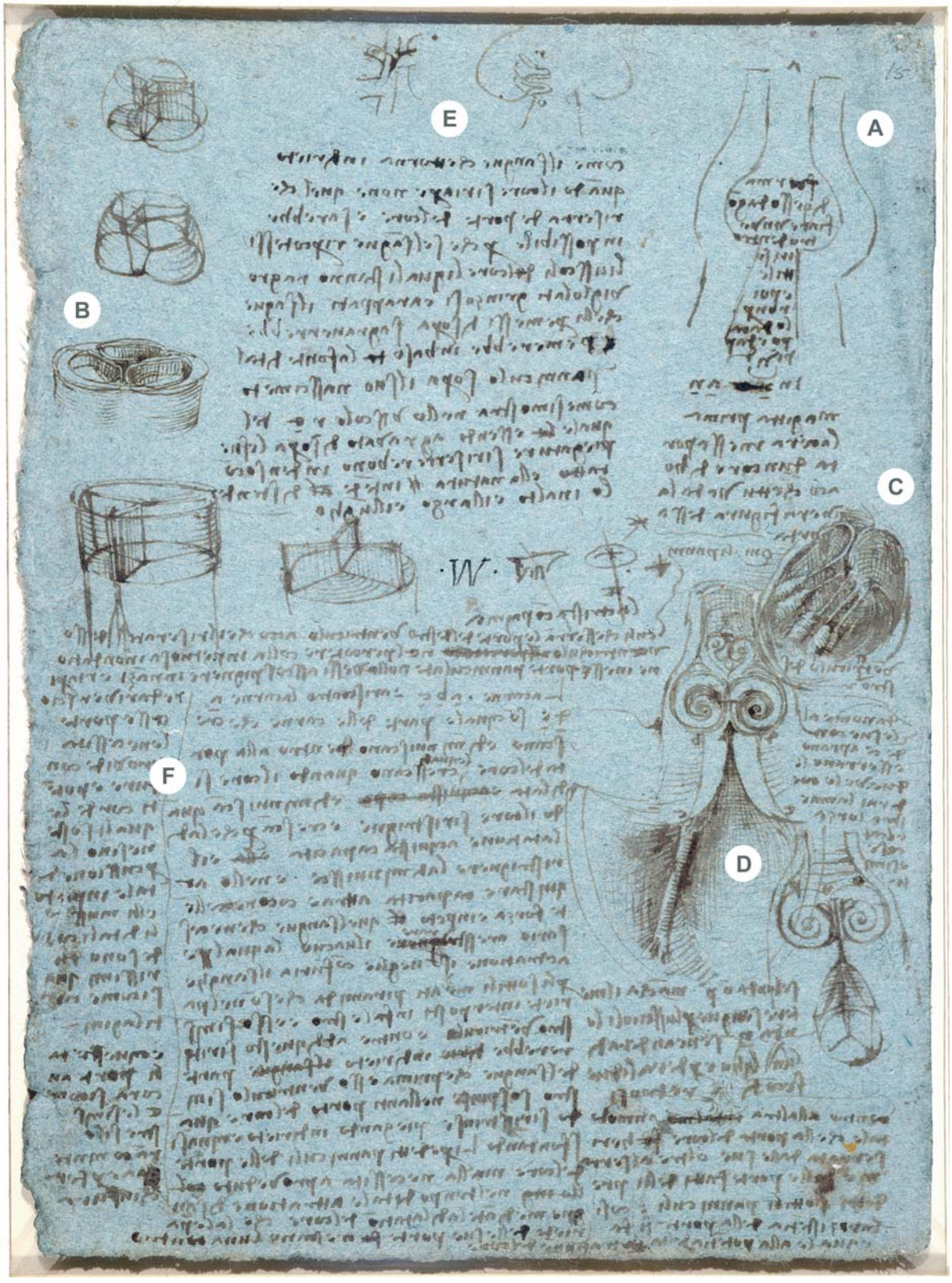

Figure 1. Leonardo da Vinci. The blood flow through the aorta (about 1513), brown ink on paper, The Royal Collection 2009, Her Majesty Queen Elizabeth II, RL 19082r.

Leonardo da Vinci: achievements and non-achievements

Leonardo refers in his notes on the heart to medical scholars like Galenus (131-199), Avicenna (980-1037) and especially the anatomist Mondino dei Liuzzi (1275-1326). In many ways, Leonardo's ideas are closer to these predecessors than to William Harvey (1578-1657). Leonardo never surpassed, for example, the ancient concept of Galenus that blood moved towards the periphery to be consumed by the organs and tissues. In the remaining notebooks there is no evidence that he ever considered the concept of circulation.

In many ways, however, Leonardo left Galenus far behind. Apart from the achievements mentioned here above, he dedicates many pages of his notebooks to his discovery of the function of the atria, which his predecessors ignored. And to mention just a few more: he describes the heart as a muscle, understands the role of the coronary vessels and is the first to mention the moderator band and the relation of the systole to the pulse.

Yet it would be a mistake, I think, to include his achievements in a history of modern science. Leonardo's drawings and notes are fragmentary and meant for his own use only. Looking at the fragments it is not hard to find evidence for more general ideas, but Leonardo rarely took the time to work these out, let alone publish them. The fragmentary notes and drawings had to wait for publication until the 19th century.

Most scholars on the history of science nowadays agree that modern science emerges in Europe only a century after Leonardo's death, in a completely different world of systematic research, publication and competition among scientists. With good reason this seventeenth century phenomenon has been called a scientific revolution.[20] A history of medical science should preferably begin with the well-known publication on the circulation by William Harvey in 1628.[21]

However, Leonardo's notes and drawings on the heart are a fine example of what an open mind and keen observation may achieve. I am looking forward to the upcoming book by Francis C. Wells, in which Leonardo's study of the heart will be discussed at length.[22] According to Wells, Leonardo's approach is 'a paradigm for modern clinical research'.[23] ■

Notes

1 The English physician Kenneth D. Keele (1909-1987) was a specialist on the subject of Leonardo as a precocious 'scientist' and author of many articles and books on Leonardo and the heart. Keele published his first book on Leonardo more than half a century ago (*Leonardo da Vinci on movement of the heart and blood*, London 1952) and his last shortly before his death (*Leonardo da Vinci's elements of the science of man*, New York 1983).
2 In this context the terms 'atherosclerosis'and 'sinus of Valsalva' are of course anachronistic. The term 'arteriosclerosis' (as equivalent of 'atherosclerosis') was probably introduced in 1833 and the term 'sinus of Valsalva' in 1740. According to KD Keele 'Leonardo da Vinci's views on arteriosclerosis', *Med Hist.* 1973 Jul;17(3):307 the term 'arteriosclerosis' was introduced by JF Lobstein in: *Traité d'Anatomie Pathologique*, Paris 1829-33, vol. 2, p. 550. The term 'sinus of Valsalva' was first used by GB Morgagni, a pupil of Antonio Maria Valsalva (1666-1723), in: *De vita et scriptis Antonii Mariae Valsalvae commentariolum*, Venice, 1740.
3 Keele 1973, op.cit. (note 1), p. 305.
4 Ibidem
5 Ibidem
6 Ibidem
7 Ibidem
8 Ibidem
9 Ibidem
10 Ibidem
11 Ibidem
12 Keele 1973, op.cit. (note 1), p. 304.
13 The articles by Bellhouse and his group as well as others are discussed by Robicsek F, 'Leonardo da Vinci and the Sinuses of Valsalva'. Ann Thorac Surg. 1991;52;328-35, p. 328.
14 Robicsek 1991, op.cit. (note 13).
15 The notes and drawings on the aortic valve are reproduced, explained and transcribed in O'Malley CD & Saunders JB de CM. *Leonardo da Vinci on the Human Body*, New York 1952. The quote is found on p. 264.
16 For example O'Malley 1952, op.cit. (note 15), pp. 260, 266, 268.
17 O'Malley 1952, op.cit. (note 15), p. 264.
18 O'Malley 1952, op.cit. (note 15), p. 266.
19 O'Malley 1952, op.cit. (note 15), p. 264..\
20 Cohen HF. *De herschepping van de wereld*. Amsterdam 2007. An extensive English version will appear in 2009 as *How Modern Science Came Into the World. A Comparative History*. Chicago 2009.
21 Harvey W. *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus*, Frankfurt 1628.
22 Wells FC, Clayton M. *The Heart of Leonardo*. Prestel Publishing, New York (expected in 2009).
23 Wells FC, 'Leonardo da Vinci as a Paradigm for Modern Clinical Research'. J Thorac Cardiovasc Surg. 2004;127:929-44.